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## Effect on the insulation material of a MOSFET device submitted to a standard diagnostic radiation beam

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**Abstract.** MOSFET electronic devices have been used for dosimetry in radiology and radiotherapy. Several communications show that due to the radiation exposure defects appear on the semiconductor crystal lattice. Actually, the structure of a MOSFET consists of three materials: a semiconductor, a metal and an insulator between them. The MOSFET is a quadripolar device with a common terminal: gate-source is the input; drain-source is the output. The gate controls the electrical current passing through semiconductor medium by the field effect because the silicon oxide acts as insulating material. The proposal of this work is to show some radiation effects on the insulator of a MOSFET device. A 6430 Keithley sub-femtoamp SourceMeter was used to verify how the insulating material layer in the structure of the device varies with the radiation exposure. We have used the IEC 61267 standard radiation X-ray beams generated from a Pantak industrial unit in the radiation energy range of computed tomography. This range was chosen because we are using the MOSFET device as radiation detector for dosimetry in computed tomography. The results showed that the behaviour of the electrical current of the device is different in the insulator and semiconductor structures.

### 1. Introduction

The use of metal oxide semiconductor field effect transistor (MOSFET) as dosimeters has been increased. Their small physical size, good spatial resolution, simple use, dose integration properties and the availability of real time data make them attractive detectors for radiation dosimetry. The main disadvantage, however, is their limited useful life due to the damage from the accumulated dose [1]. The principle in operation of MOSFET dosimetry is based on the generation of electron-hole pairs in the semiconductor region due to the interaction of the ionizing radiation. The changing in the semiconductor material occurs each time it is irradiated and its electrical characteristics can demonstrate how its response is. The behaviour of the device response when it is submitted to a radiation beam allows the health physical scientists make analysis about the entrance dose in a patient undergoing a radiodiagnostic examination and radiotherapy, for while [2-4]. The purpose of this study

was to investigate the radiation effects on the insulator of a MOSFET device applying radiation beam normally used in the computed tomography.

## 2. Materials and methods

There are several MOSFET type devices commercially available. One of most used is the N channel MOSFET. Such a device has a *p*-type silicon semiconductor substrate separated from a metal gate by an insulating oxide layer. Two of its terminals called the source (S) and the drain (D) corresponds to two negatively doped (n type) silicon parts. The third terminal is the gate (G) (Fig. 1a). Five identical BSS138N MOSFET (Fig. 1b) devices were used aiming to make analysis how this detector type responds to radiation beam chosen, and one of them was not irradiated for monitoring the devices. BSS138N device has a Surface Mount Device (SMD) encapsulation [5].

An HF320 Pantak X-ray unit was used to generate filtered X-ray beam (Fig. 2a): the RQR9 standard radiation quality, chosen based on the IEC 61627, which is employed in computed tomography application. For all measurements the devices were positioned with the black epoxy layer opposite to the incident beam for direct fixation at the centre of the respective applicators (closed).

There are two ways to test MOSFET devices in radiation field: active and passive mode [6]. The last one was used in this work. The procedure of make measurements followed the steps: 1) reading of the gate electrical current ( $I_{GS}$ ) using a 6430 Keithley sub-femtoamp SourceMeter and reading of the drain electrical current ( $I_{DS}$ ) using a 2400 Keithley SourceMeter; 2) irradiation of the device with 25 gray accumulated dose; 3) reading after irradiation of  $I_{GS}$  and  $I_{DS}$  (Fig. 2b). This procedure was repeated systematically until 100 Gy dose. Each reading is an average of five data points. A 47 $\Omega$  resistor was used to bias the drain terminal at 10V and avoid to breakdown them. The gate-source voltage  $V_{GS}$  was chosen to be 10V.

A RC6 ionization chamber coupled to a 6517 Keithley was used to measure the dose at detector position.

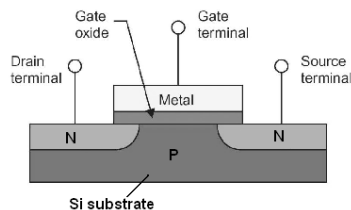


Figure 1.a) Schematic diagram of a MOSFET.

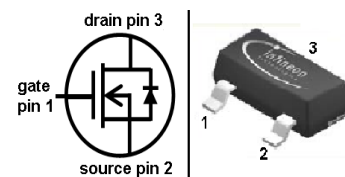


Figure 1.b) BSS138N MOSFET device [6].

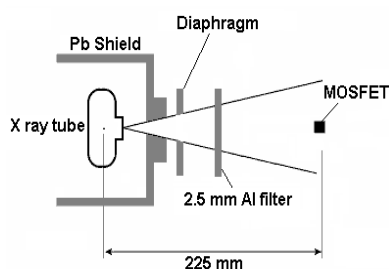


Figure 2. a) Experimental arrangement (not to scale).

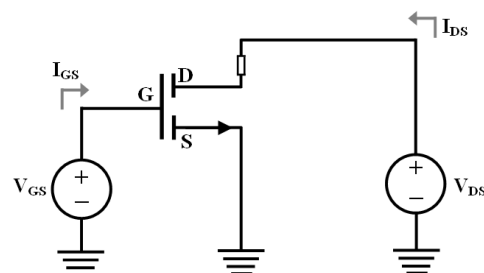


Figure 2. b) Schematic circuit of readings.

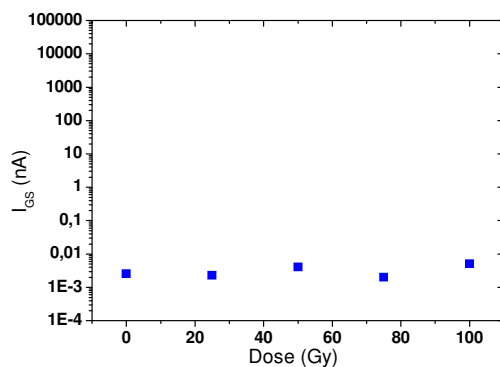
### 3. Results and discussion

Observing Table 1, which shows  $I_{GS}$  and  $I_{DS}$  data obtained before the irradiation and after 100 Gy accumulated dose, one may be noted that  $I_{GS}$  practically did not change remaining at picoampere scale. However, the semiconductor current ( $I_{DS}$ ) varied significantly, from picoampere up to microampere scale. This suggests that the silicon dioxide did not have its structure altered due to ionizing radiation from RQR9 beam quality. In fact the oxide is considered as a region with high density of defects whose charge state can be altered by irradiation. The damage to the  $SiO_2$  structure caused by the interaction of radiation manifests as a build up of positive charge due to the semipermanent trapped holes when radiation-generated electrons are diffused out of the insulator [7].

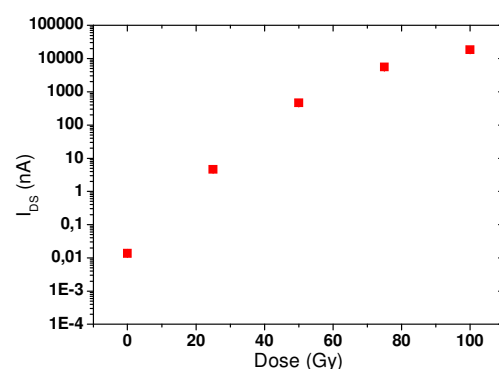
**Table 1.** Values of  $I_{GS}$  and  $I_{DS}$  current before the irradiation and after 100 Gy dose.

	$I_{GS}$ (pA) (Dose = 0 Gy)	$I_{GS}$ (pA) (Dose = 100 Gy)	$I_{DS}$ (pA) (Dose = 0 Gy)	$I_{DS}$ (μA) (Dose = 100 Gy)
<b>MFT01</b>	$0.7 \pm 0.6$	$1.0 \pm 0.5$	$19.4 \pm 3.2$	$5.632 \pm 0.006$
<b>MFT02</b>	$0.5 \pm 0.1$	$4.3 \pm 0.1$	$7.3 \pm 4.7$	$2.080 \pm 0.005$
<b>MFT03</b>	$1.7 \pm 0.3$	$5.4 \pm 1.2$	$14.3 \pm 1.5$	$9.473 \pm 0.014$

As a result, Figures 3 and 4 present the glow curve after the cumulative dose irradiation with 25 Gy intervals. The graphics are on the same scale to show more clearly the behaviour of current with cumulative dose. The radiation damage in the insulator structure of the device did not appear in form of changing in its bulk electrical characteristic (Fig. 3). However, according to Figure 4 one observes that the glow varied with the dose and that this feature can be used to relate the device response with the absorbed radiation. The total cumulative dose chosen represents more than one thousands head computed tomography examinations.



**Figure 3.** The  $I_{GS}$  current variation as a function of the dose.



**Figure 4.** The  $I_{DS}$  current variation as a function of the dose.

### 4. Conclusions

On the one hand the variation of the gate current ( $I_{GS}$ ) as a function of the cumulative dose applied to the device was not significant. For the computed tomography radiation field used to verify the electrical response of passive mode MOSFET as X-ray detector, one can conclude that the mechanism of oxide radiation damage did not alter at all the insulator structure. On the other hand, the crystal semiconductor structure of the device (drain-source and substrate) showed a variation of several orders of magnitude larger than that of insulator ( $10^6$ ). This result is expressed in terms of the semiconductor conductivity after the device to have been submitted to a 100 Gy cumulative dose.

## 5. Acknowledgments

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